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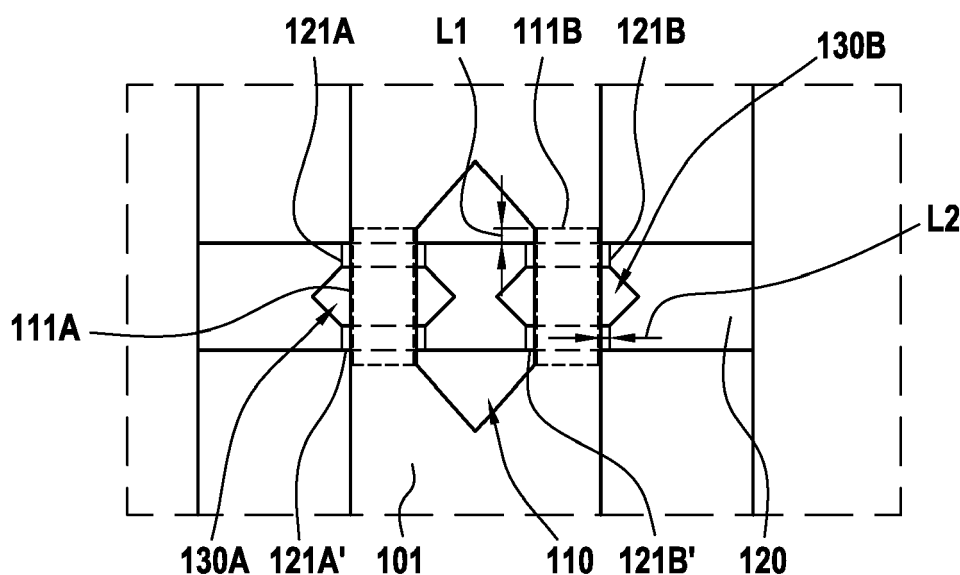
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(54) **AN ELECTRICAL DEVICE COMPRISING A COPLANAR WAVEGUIDE WITH BURIED BRIDGES AND APERTURES**

(57) An electrical device comprising a coplanar waveguide above a substrate (200) including a signal line (101) surrounded on one side by a first portion (103A) of ground plane and on another side by a second portion (103B) of ground plane, wherein the device further comprises at least one buried conductive bridge (120) forming an electrical connection between the first portion of the ground plane and to the

second portion of the ground plane, the buried bridge being perpendicular with the signal line, arranged below the signal line, and being electrically insulated from the signal line by an insulating layer (140), and wherein the signal line comprises an aperture (110) above and at the level of the buried bridge arranged so that two portions (111A, 111B) of signal line remain on each side of the aperture.

**FIG.2B**

Description

Field of the Invention

[0001] The present invention relates to the field of electrical devices comprising coplanar waveguides.

Technical Background

[0002] Coplanar waveguides comprise a single line extending, for example, in a straight line, surrounded on each side by ground planes. This configuration ensures a good transmission of the signal over a wide range of frequencies (for example from 100 kHz to 100 GHz) with minimal losses.

[0003] Silicon manufacturing technologies have been used to manufacture coplanar waveguides above substrates such as silicon substrate.

[0004] A typical application of coplanar waveguides manufactured on silicon is the manufacture of silicon interposer used to support a laser (also called optical interposers). Figure 1A is a perspective view of a device 1 which includes an optical interposer 2 in accordance with the known prior art. The interposer of this device comprises a laser module 3 which is connected on its top face to a signal line 4. The signal travelling on signal line 4 performs the operation of optical modulation. Other components 6 are also arranged on the interposer, as is customary in the art.

[0005] The signal line 4 may also be called a transmission line. In the illustrated example, the signal line 4 extends in a direction and is surrounded on one side by a portion of ground plane 5A and on the other side by a portion of ground plane 5B.

[0006] Figure 1B is a top view of the device of figure 1A, on which it can be seen that the portion 5A has a width measured between opposite edges of the portion in a direction perpendicular with the signal line 4 which is far less than the width of the portion 5B measured between opposite edges of the portion in the same direction. This results notably from the manner in which the components are connected (i.e. via wire bonding) and the quantity of components to be arranged on the interposer. The portion 5A also has a width which is comparable to the width of the signal line 4A.

[0007] This width difference, and the limited width of the portion 5A, is known to cause an imbalance in the ground planes, which then causes an increase of the impedance of the narrower portion. Consequently, there is an imbalance in the return current paths. This has been observed to cause resonances and losses in the transmission of signals at given frequencies.

[0008] It is thus desirable to redirect a portion of the return current passing through the wider portion of the ground plane to the other portion, so as to equilibrate the operation of the coplanar waveguide.

[0009] Several propositions have been made in the prior art.

[0010] Document "Excitation of coupled slotline mode in finite-ground CPW with unequal ground-plane widths" (Published in: IEEE Transactions on Microwave Theory and Techniques (Volume: 53, Issue: 2, Feb. 2005)) discloses a structure in which bridges join the two portions of ground planes. These bridges are separated from the signal line by air and are consequently formed using a sacrificial layer which supports the bridge in the initial manufacturing stages. This solution is inappropriate and too complex for large scale manufacturing of devices.

[0011] It should be noted that the separation by air is a solution to the apparition of parasitic capacitors between the signal line and the bridge which may be too problematic given the permittivity of insulating materials which may separate the bridge from the signal line.

[0012] Documents "Fabrication of Al air-bridge on coplanar waveguide" (Jin Zhen-Chuan, Wu Hai-Teng, Yu Hai-Feng, Yu Yang. Chinese Physics B, 2018, 27(10): 100310), "A 0-55-GHz Coplanar Waveguide to Coplanar Strip Transition" (Anagnostou, Dimitris & Morton, Matt & Papapolymerou, John & Christodoulou, Christos. (2008). Microwave Theory and Techniques, IEEE Transactions on. 56. 1 - 6. 10.1109/TMTT.2007.911909), "Progress in Antenna Coupled Kinetic Inductance Detectors" (Baryshev, Andrey & Baselmans, J.J.A. & Freni, A. & Gerini, Giampiero & Hoevers, H. & Iacono, Annalisa & Neto, A.. (2011). IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY. 1. 10.1109/TTHZ.2011.2159532), and "Effects of air-bridges and mitering on coplanar waveguide 90 degrees bends: theory and experiment" (Omar, Amjad & Chow, Y.L. & Roy, Langis & Stubbs, M.G. (1993). 823 - 826 vol.2. 10.1109/MWSYM.1993.276748), and US 7990237 all disclose similar bridged structures, which can be designated under the expression "air bridge". These structures are also too complex to manufacture.

[0013] In document "Microstrip, Stripline, CPW, and SIW Design" (Iulian Rosu, YO3DAC/VA3IUL, downloadable in December 2020 at URL: [https://www.qsl.net/va3iul/Microstrip Stripline CPW Design/Microstrip Stripline and CPW Design.pdf](https://www.qsl.net/va3iul/Microstrip%20Stripline%20CPW%20Design/Microstrip%20Stripline%20and%20CPW%20Design.pdf)), it is also proposed to use vertical vias to connect the portions of ground plane to another ground plane arranged at the bottom of the interposer. This results in buried bridges being formed. This solution is also too complex to implement.

[0014] Document "Design and Modeling of 60-GHz CMOS Integrated Circuits" (Chinh, Ha. 2020) also discloses buried bridges, but these bridges still result in capacitive couplings between signal lines and buried bridges.

[0015] Document « (Sub) mm-wave Calibration » (M. Spirito, L. Galatro, 2018) also discloses the issues of known structures.

[0016] The present invention has been made in the light of the above problems.

Summary of the Invention

[0017] The present invention provides an electrical device comprising a coplanar waveguide above a substrate including a signal line surrounded on one side by a first portion of ground plane and on another side by a second portion of ground plane, wherein the first portion has a width measured from the edge facing the signal line to the opposite edge which is smaller than the width of the second portion measured from the edge facing the signal line to the opposite edge,

wherein the device further comprises at least one buried conductive bridge forming an electrical connection between the first portion of the ground plane and to the second portion of the ground plane, the buried bridge being perpendicular with the signal line (for example its edges are perpendicular with the edges of signal line), arranged below the signal line, and being electrically insulated from the signal line by an insulating layer, and wherein the signal line comprises an aperture above and at the level of the buried bridge arranged so that two portions of signal line remain on each side of the aperture (for example when looking at the device from the top, the aperture is directly above a portion of buried bridge).

[0018] The above device therefore uses a buried bridge to equilibrate the return current in the two ground planes where one is narrower than the other.

[0019] It has been observed by the inventors of the present invention that the current may travel on the outer portions of the signal line in the direction of the signal line (in a skin-effect manner). Consequently, forming an aperture in the middle of the signal line while maintaining two portions of signal lines on each side of the aperture does not affect too greatly the impedance of the signal line (a loss may be observed for low frequencies). Furthermore, the aperture limits capacitive couplings from appearing between the buried bridge and the signal line.

[0020] Consequently, the return currents can be equilibrated between the two ground planes without introducing parasitic capacitive couplings.

[0021] The buried bridge and the signal line are both formed above the substrate; hence, they can be connected without using a vertical interconnection. The substrate supporting the coplanar waveguide and the buried bridge can be, for example, a semiconductor substrate (typically comprising silicon). Thus, manufacturing the coplanar waveguide can involve semiconductor manufacturing technologies.

[0022] According to a particular embodiment, the signal line presents a plane of symmetry extending through the middle of the signal line and perpendicular with the plane in which the signal line extends.

[0023] By perpendicular the plane of symmetry is in fact perpendicular to the general direction defined by the signal line. This arrangement ensures that the current passes evenly on each side of the aperture.

[0024] According to a particular embodiment, the aperture has a length measured in the direction of the signal

line which is greater than the width of the buried bridge measured in the direction of the signal line (or in a direction which is perpendicular with the direction of the buried bridge, i.e. the general direction defined by the buried bridge).

[0025] This particular embodiment ensures that the only the side portions of the signal line remain above the buried bridge so that the parasitic capacitive couplings are greatly limited.

[0026] According to a particular embodiment, the aperture has parallel edges over the buried bridge.

[0027] According to a particular embodiment, the parallel edges exceed the width of the buried bridge by a given distance measured from each edge of the buried bridge.

[0028] This particular configuration has been observed to greatly limit parasitic couplings between the buried bridge and the signal line.

[0029] According to a particular embodiment, the given distance is greater or equal than the thickness of the signal line and greater or equal than the thickness of the buried bridge.

[0030] This rule has been observed to provide a good limitation of parasitic couplings.

[0031] According to a particular embodiment, the buried bridge comprises two apertures, each aperture being arranged below and at the level of a respective remaining portion of signal line on each side of the aperture of the signal line, the two apertures being arranged so that two portions of buried bridge remain on each side of each aperture of the two apertures.

[0032] It has also been observed that in the buried bridge, the current travels in the outer portions of the buried bridge. Hence, forming apertures in the buried bridge may not affect too greatly the impedance of the buried bridge (a loss may be observed for low frequencies).

[0033] These two apertures in the buried bridge will further limit parasitic capacitive couplings which may appear between what the portions of the signal line which remain and the buried bridge.

[0034] The apertures of the buried bridge may have the same geometrical characteristics as the aperture of the signal line, with respect to the corresponding portions of signal line instead of the buried bridge.

[0035] According to a particular embodiment, the buried bridge presents a plane of symmetry extending through the middle of the buried bridge and perpendicular with the plane in which the buried bridge extends.

[0036] According to a particular embodiment, the apertures of the buried bridge have a length measured in the direction of the buried bridge which is greater than the width of each portion of signal line measured in the direction of the buried bridge.

[0037] According to a particular embodiment, the apertures of the buried bridge have parallel edges below each corresponding portion of signal line.

[0038] According to a particular embodiment, the par-

allel edges of the apertures of the buried bridge exceed the width of the corresponding portion of signal line by a second given distance measured from each edge of the corresponding portion of signal line.

[0039] According to a particular embodiment, the given distance is greater or equal than the thickness of the buried bridge and greater or equal than the thickness of the signal line.

[0040] It has been observed by the inventors of the present invention that an excess of length of the apertures which is greater than the thicker of the two thicknesses will significantly limit the parasitic capacitive couplings between the portions of signal line and the buried bridge.

[0041] According to a particular embodiment, the device comprises a plurality of identical parallel buried bridges, and the signal line comprises a plurality of identical apertures aligned in the direction of the signal line, each aperture being arranged above and at the level of a corresponding buried bridge.

[0042] The buried bridges may be evenly spaced, and may all have the same geometrical characteristics. Also, the apertures (in the signal line or in the buried bridge) may all be identical between the different sets of buried bridge and aperture of the signal line.

[0043] The invention also provides an optical interposer comprising an electrical device as defined above.

[0044] For example, this optical interposer may comprise a laser module connected to the signal line.

Brief Description of the Drawings

[0045] Further features and advantages of the present invention will become apparent from the following description of certain embodiments thereof, given by way of illustration only, not limitation, with reference to the accompanying drawings in which:

- Figures 1A and 1B, already described, show device according to the prior art,
- Figure 2A and 2B are top views of a device in accordance with an example,
- Figures 3 to 7 are different cross sections of the device of figures 2A and 2B,
- Figures 8A and 8B illustrate the current density in the device,
- Figure 9 is a graph showing the insertion losses for various devices.

Detailed Description of Example Embodiments

[0046] We will now describe an electrical device comprising a coplanar waveguide in which the signal line comprises apertures above buried bridges.

[0047] The devices of the invention can be implemented in an optical interposer, for example by substituting the optical interposer described in reference to figures 1A and 1B with a device which will be described herein-

after.

[0048] The invention is however not limited to optical interposers and is applicable to other systems in which a coplanar waveguide is used but is surrounded by portions of ground planes having different widths.

[0049] Also, while the invention is shown in the present description using straight signal lines as an example, the invention also applies to signal lines having turns, which can be considered to be a plurality of individual signal lines each having a general direction which is straight and under which perpendicular buried bridges can be formed.

[0050] Figure 2A is a top view of a device 100 which comprises a coplanar waveguide including a signal line 101. The signal line 101 extends between two ends 102A and 102B. By way of example, wires may be bonded to the signal line 101 in the vicinity of both ends 102A and 102B. The coplanar waveguide also includes a portion of ground plane 103A on the left side of the signal line on the figure and a portion of ground plane 103B on the right side of the signal line on figure. The left side portion 103A has a width WA, measured from the edge facing the signal line to its opposite edge, which is smaller than the width WB of the right side portion 103B measured from the edge facing the signal to the opposite edge.

[0051] In the illustrated example, the width WA is comparable and even smaller than the width of the signal line 101. This is likely to cause resonances and loss in the transmission of signals in the signal line 101 as it is usually preferable in a coplanar waveguide to have ground planes which are at least several times the width of the signal line (for example three times).

[0052] To overcome this issue, the device is provided with buried bridges 120 and six buried bridges 120 are represented on the figure. The number of bridges to be used can be determined in accordance with the highest frequency under which the device will be operated and more precisely in accordance with the wavelength corresponding to this frequency. It is recommended to implement buried bridges separated by a distance which can be of the order of a tenth of this wavelength or a twentieth of this wavelength. For example, if the device will be used for frequencies reaching up to 100 GHz (wavelength of about 3mm), the buried bridges should be arranged every 300µm or every 150µm. The buried bridge and the signal line are separated by an insulating layer in a manner which will become clearer hereinafter in reference to figures 3 to 7.

[0053] It is proposed to limit parasitic couplings between the signal line 101 and the buried bridge 120 by forming apertures 110 in the signal line above (when seen from the top as shown on the present figure 2A) each buried bridge 120. All the apertures and buried bridges are identical in the illustrated example.

[0054] Figure 2B is a more detailed view of an area comprising a buried bridge 120 below an aperture 110. The portion corresponding to figure 2B is designated as IIB on figure 2A.. On this figure, it can be seen that the

aperture is arranged between two portions of signal line 111A and 111B.

[0055] It can also be seen that the aperture has a shape and is arranged in a manner which makes the signal line 101 symmetrical: there is a plane of symmetry perpendicular to the plane in which the signal line extends and extending through the middle of the signal line.

[0056] Also, the aperture 110 is longer than the width of the buried bridge. More precisely, the aperture has two parallel edges which extend over and further (in the direction of the top and in the direction of the bottom) than the buried bridge.

[0057] While not mandatory, the aperture has a hexagonal shape: the two parallel edges are joined by a tapered end on each side of the buried bridge.

[0058] It should be noted that the aperture should preferentially be longer than the width of the buried bridge, but that its length should be limited so as to limit the impact on the resistance of the signal line. It should be noted that forming apertures in a signal line goes against the traditional approach of the person skilled in the art, however, the inventors of the present invention have observed that because the current mostly travels in the outer portions of the signal lines, the apertures do not impact the impedance of the signal line too much.

[0059] By way of example, the parallel edges can extend further than the buried bridge for a distance L1 which can be greater or equal than the thickness of the signal line and greater or equal than the thickness of the buried bridge. The tapered end should have a limited length.

[0060] As can be seen on the figure, in order to limit parasitic couplings between the remaining portions 111A and 111B and the buried bridge, two apertures 130A (below the portion 111A) and 130B (below the portion 111B) have been formed in the buried bridge.

[0061] On the sides of the aperture 130A of the buried bridge, there remains two portions 121A and 121A' of buried bridge. On the sides of the aperture 130B of the buried bridge, there remains two portions 121B and 121B' of buried bridge.

[0062] The apertures 130A and 130B of the buried bridge are geometrically equivalent to the aperture 110 of the signal line but take a portion of signal line 111A or 111B as reference instead of the buried bridge.

[0063] It can be seen that the apertures 130A and 130B have a shape and are arranged in a manner which makes the buried bridge symmetrical: there is a plane of symmetry perpendicular to the plane in which the buried bridge extends and passing through the middle of the buried bridge.

[0064] Also, the apertures 130A and 130B are longer than the width of the portions 111A and 111B. More precisely, the apertures have two parallel edges which extend over and further (in the direction of the right and in the direction of the left on the figure) than these portions.

[0065] While not mandatory, the apertures 130A and 130B have a hexagonal shape: the two parallel edges are joined by a tapered end on each side of the corre-

sponding portion (111A or 111B).

[0066] It should be noted that the aperture should preferentially be longer than the width of portions of signal line, but that their length should be limited so as to limit the impact on the resistance of the buried bridge. It should be noted that forming apertures in a buried bridge goes against the traditional approach of the person skilled in the art, however, the inventors of the present invention have observed that because the current mostly travels in the outer portions of the buried bridges, the apertures do not impact the impedance of the buried bridge too much.

[0067] By way of example, the parallel edges can extend further than the portions for a distance L2 which can be greater or equal than the thickness of the buried bridge and of the signal line. The tapered end should have a limited length.

[0068] Figure 3 is a cross section of the device of figures 2A and 2B, along plane A-A' also shown on the figure.

[0069] On this figure, it can be seen that the device is formed on a substrate 200, here a silicon substrate. Above the substrate, a first metal layer (for example comprising aluminum) is formed and patterned to obtain the buried bridge 120, portions of it being visible on figure 3 (all the buried bridges are formed simultaneously in this step). The first metal layer and the formed buried bridges can have a thickness of the order of 1 micrometer.

[0070] Above the buried bridges, an insulating layer 140 has been formed and this layer can comprise, for example, silicon dioxide. This layer may have a thickness of about 0.4 micrometer. This layer is also patterned so as that portions of the buried bridges remain exposed and unprotected where the portions of ground planes will contact the buried bridges.

[0071] Above the insulating layer 140, a second metal layer (for example comprising aluminum) is formed and patterned so as to form the signal line and the ground plane. This layer can have a thickness of 3 micrometers (the signal line is thicker than the buried bridge and this thickness will be taken into account when determining lengths L1 and L2).

[0072] Additionally, a passivation layer 150 (typically comprising silicon nitride) is formed above the structure.

[0073] In the cross section of figure 3, which passes through the middle of the buried bridge and extends in the direction of the buried bridge, the aperture 110 can be seen with the two portions 111A and 111B of signal line remaining. There are apertures 130A and 130B in the buried bridge below these portions and as can be seen on the figure, these two apertures are larger than the portions of signal line which remain.

[0074] Figure 4 is a cross section along plane B-B' also shown on the figure. This plane passes where the buried bridge 120 is fully present below portions 111A and 111B of the signal line.

[0075] Figure 5 is a cross section along plane C-C' also shown on the figure. This plane passes in a portion where

there is no buried bridge but tapered portions 112A and 112B of the signal line are visible.

[0076] Figure 6 is a cross section along plane D-D' also shown on the figure. This plane is the plane of symmetry of the signal line. Hence, the aperture 110 is visible as well as the buried bridge 120 in the middle.

[0077] Figure 7 is a cross section along plane E-E' also shown on the figure. This plane is parallel to plane D-D' but passes in the middle of the portion 111A of the signal line. Hence, the aperture 130A of the buried bridge is visible surrounded by portions 121A' and 121A.

[0078] Figure 8A shows the simulated current density in the device when it is operated at 60GHz. The lighter shade on the edges of the signal line shows how the aperture does not affect the current too much.

[0079] Figure 8B shows the simulated current density in a buried bridge. The lighter shade on the edges of the buried bridge also indicate that the apertures in the buried bridge do not affect the travel of current in the buried bridge.

[0080] Figure 9 is a graph which shows the insertion losses in dB with respect to the frequency for:

- 1: a balanced device having two portions of ground planes of equal width;
- 2: an unbalanced device having a portion of ground plane wider than the other;
- 3: a device with buried bridges with no apertures; and
- 4: a device as shown in reference to figures 2A to 7.

[0081] The balanced device represents an ideal case, although it is unsuitable for some applications as it prevents connecting some components.

[0082] The unbalanced device shows multiple resonances and a strong loss at about 70 GHz.

[0083] The bridged device also shows multiple resonances.

[0084] The device in accordance with the example described in the present description present a great diminution of losses with respect to the unbalanced and bridge cases.

[0085] The present invention therefore improves the transmission of signals in coplanar waveguides and is particularly suitable for devices formed using silicon manufacturing technologies.

[0086] In particular, the present invention is suitable to form optical interposers.

Claims

1. An electrical device comprising a coplanar waveguide above a substrate (200) including a signal line (101) surrounded on one side by a first portion (103A) of ground plane and on another side by a second portion (103B) of ground plane, wherein the first portion has a width measured from the edge facing the signal line to the opposite edge which is

smaller than the width of the second portion measured from the edge facing the signal line to the opposite edge,

wherein the device further comprises at least one buried conductive bridge (120) forming an electrical connection between the first portion of the ground plane and to the second portion of the ground plane, the buried bridge being perpendicular with the signal line, arranged below the signal line, and being electrically insulated from the signal line by an insulating layer (140),

and wherein the signal line comprises an aperture (110) above and at the level of the buried bridge arranged so that two portions (111A, 111B) of signal line remain on each side of the aperture.

2. The device in accordance with claim 1 wherein the signal line presents a plane of symmetry (D-D') extending through the middle of the signal line and perpendicular with the plane in which the signal line extends.
3. The device in accordance with claim 1 or 2, wherein the aperture has a length measured in the direction of the signal line which is greater than the width of the buried bridge measured in the direction of the signal line.
4. The device in accordance with any one of claims 1 to 3, wherein the aperture has parallel edges over the buried bridge.
5. The device of claims 3 and 4, wherein the parallel edges exceed the width of the buried bridge by a given distance (L1) measured from each edge of the buried bridge.
6. The device of claim 5, wherein the given distance is greater or equal than the thickness of the signal line and greater or equal than the thickness of the buried bridge.
7. The device of any one of claims 1 to 6, wherein the buried bridge comprises two apertures (130A, 130B), each aperture being arranged below and at the level of a respective remaining portion of signal line on each side of the aperture of the signal line, the two apertures being arranged so that two portions (121A, 121A', 121B, 121B') of buried bridge remain on each side of each aperture of the two apertures.
8. The device of claim 7, wherein the buried bridge presents a plane of symmetry (A-A') extending through the middle of the buried bridge and perpendicular with the plane in which the buried bridge extends.

9. The device of claims 7 or 8, wherein the apertures of the buried bridge have a length measured in the direction of the buried bridge which is greater than the width of each portion of signal line measured in the direction of the buried bridge. 5
10. The device of any one of claims 7 to 9, wherein the apertures of the buried bridge have parallel edges below each corresponding portion of signal line. 10
11. The device of claims 9 and 10, wherein the parallel edges of the apertures of the buried bridge exceed the width of the corresponding portion of signal line by a second given distance (L2) measured from each edge of the corresponding portion of signal line. 15
12. The device of claim 11, wherein the given distance is greater or equal than the thickness of the buried bridge and greater or equal than the thickness of the signal line. 20
13. The device of any one of claims 1 to 12, further comprising a plurality of identical parallel buried bridges, and wherein the signal line comprises a plurality of identical apertures aligned in the direction of the signal line, each aperture being arranged above and at the level of a corresponding buried bridge. 25
14. An optical interposer comprising an electrical device in accordance with any one of claims 1 to 10. 30

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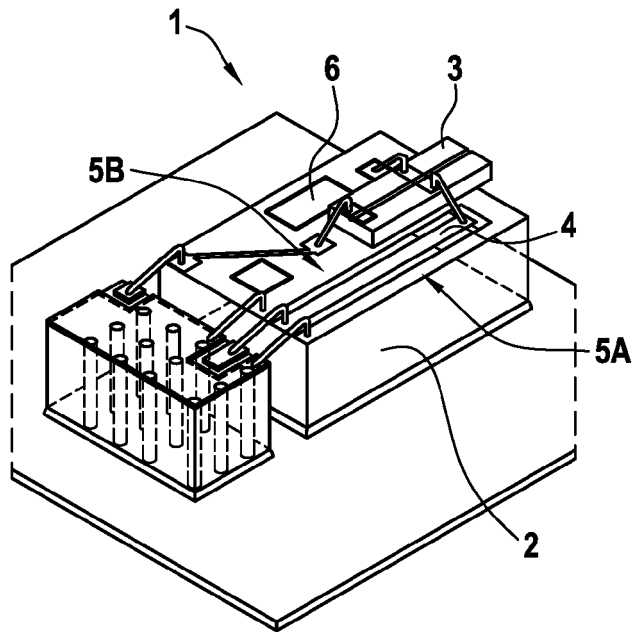


FIG.1A

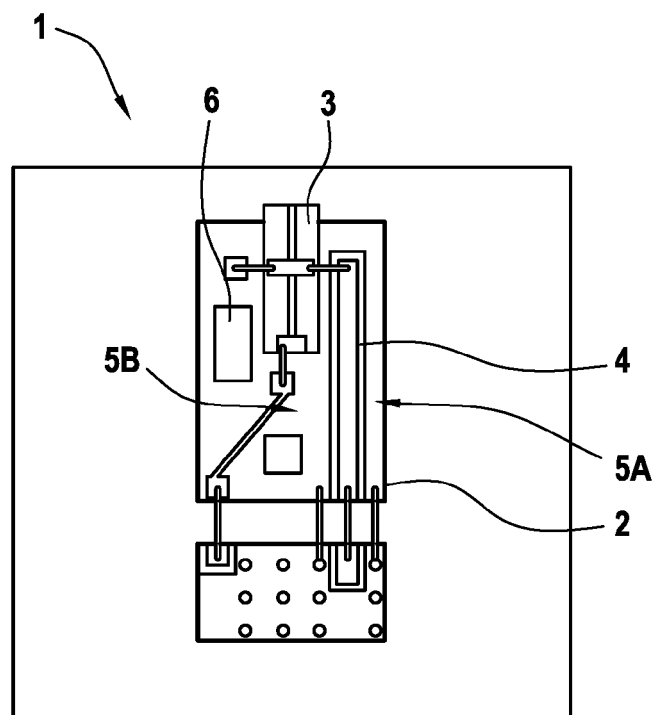


FIG.1B

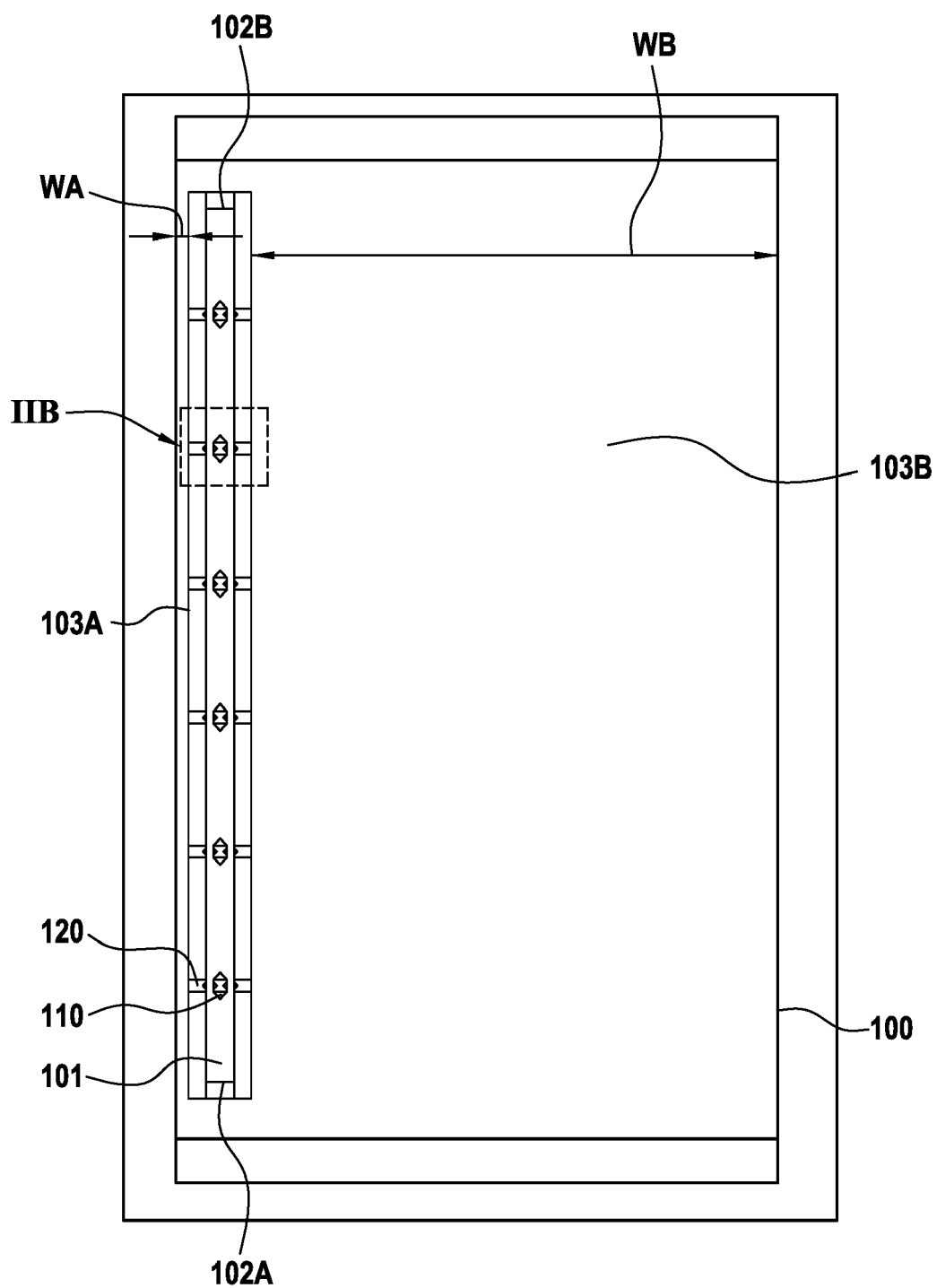


FIG.2A

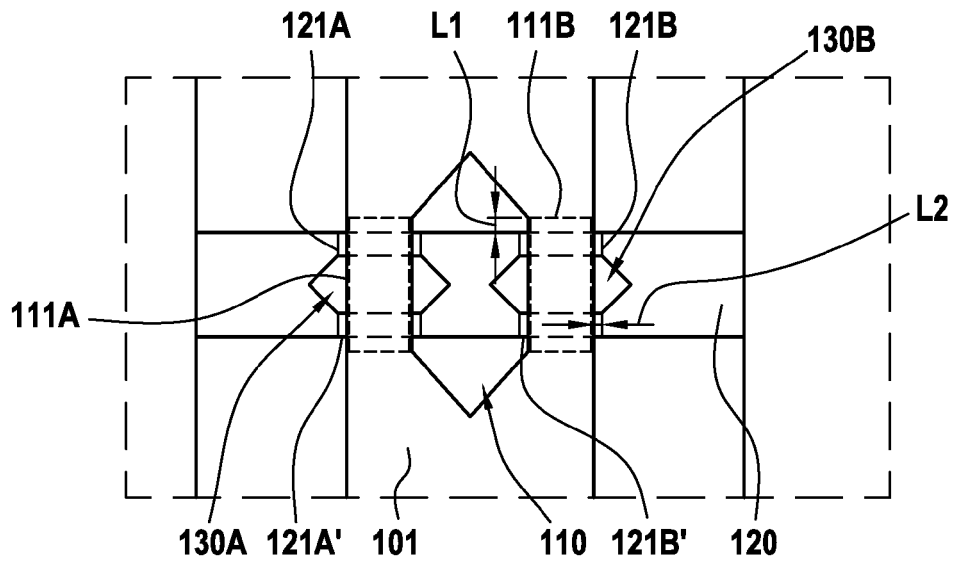


FIG. 2B

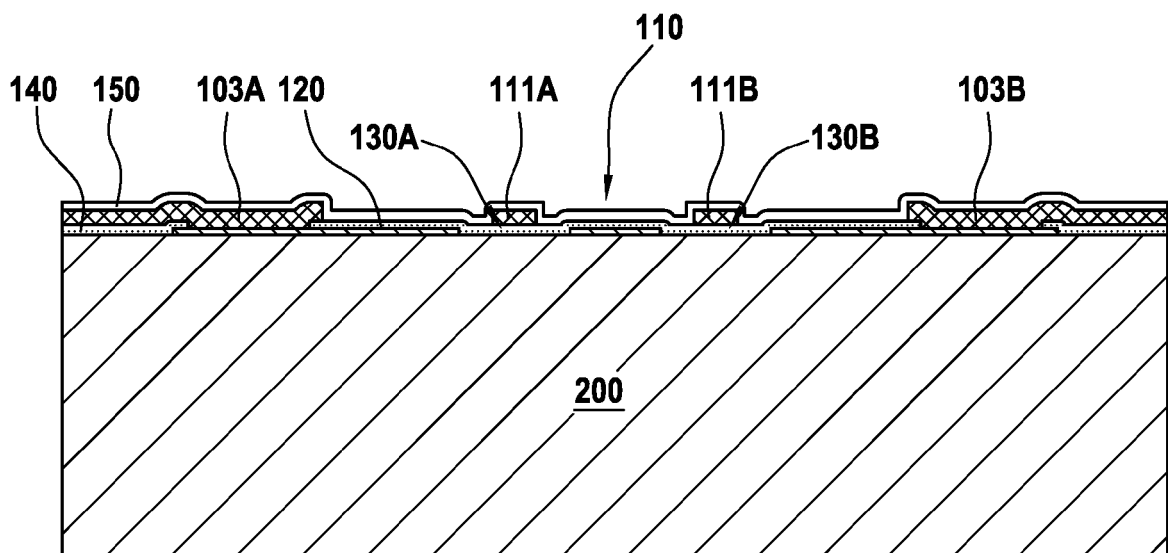
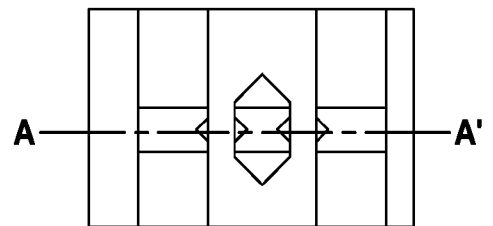


FIG. 3

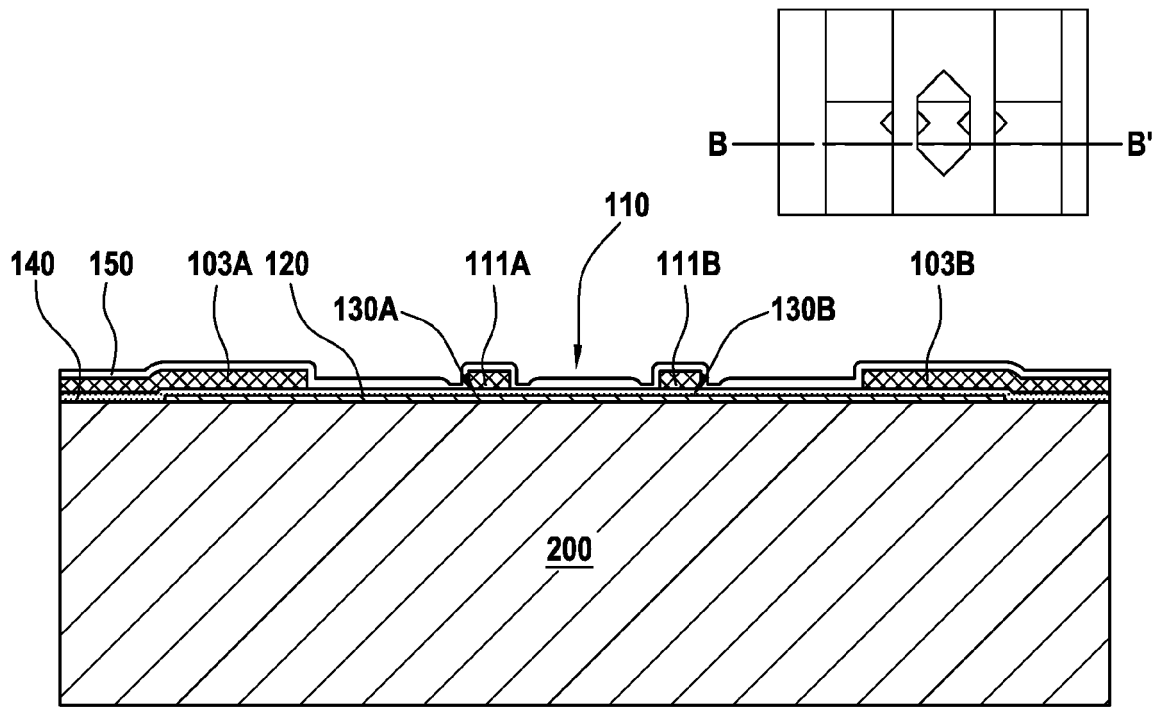


FIG. 4

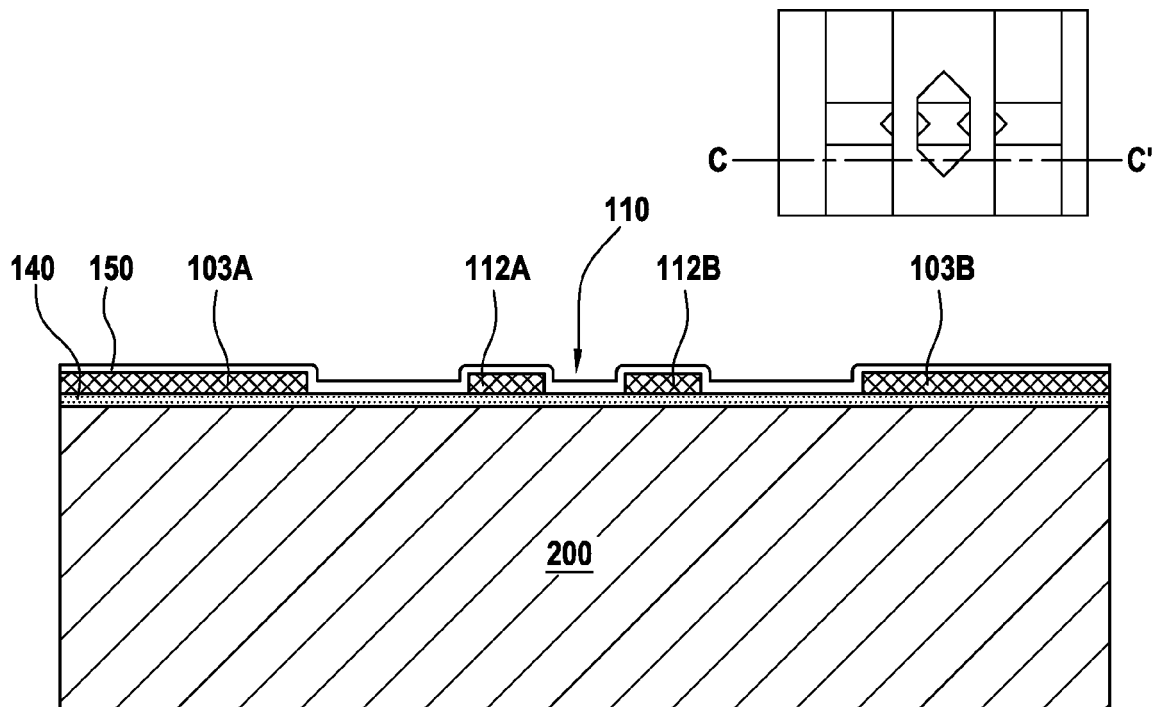


FIG. 5

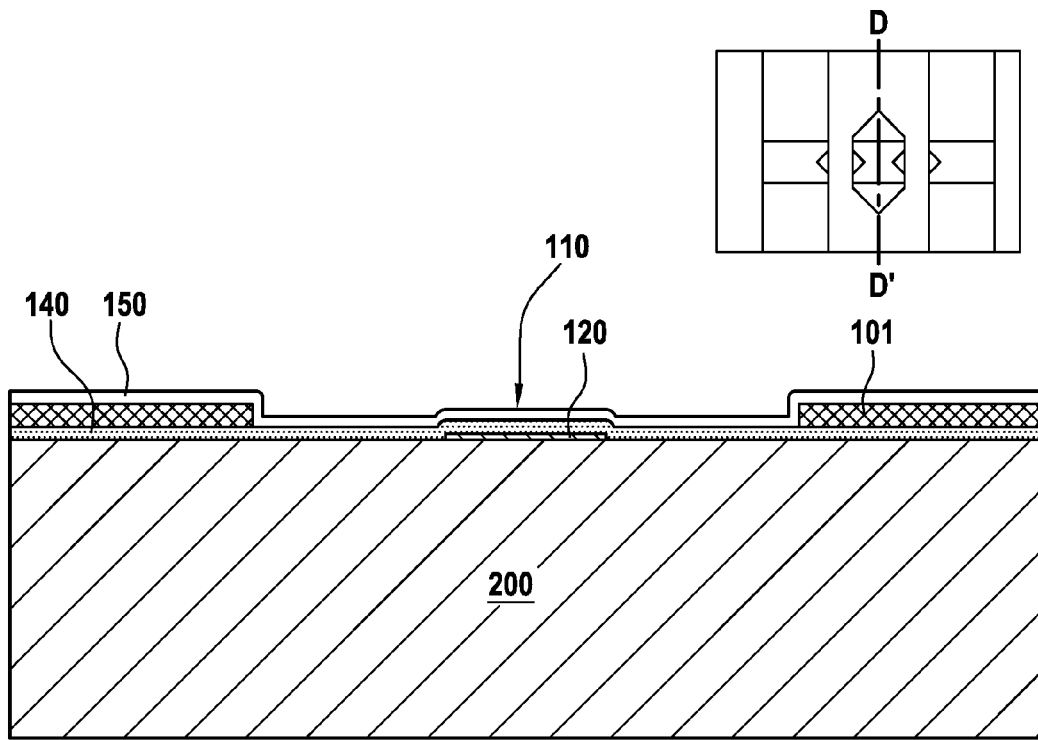


FIG. 6

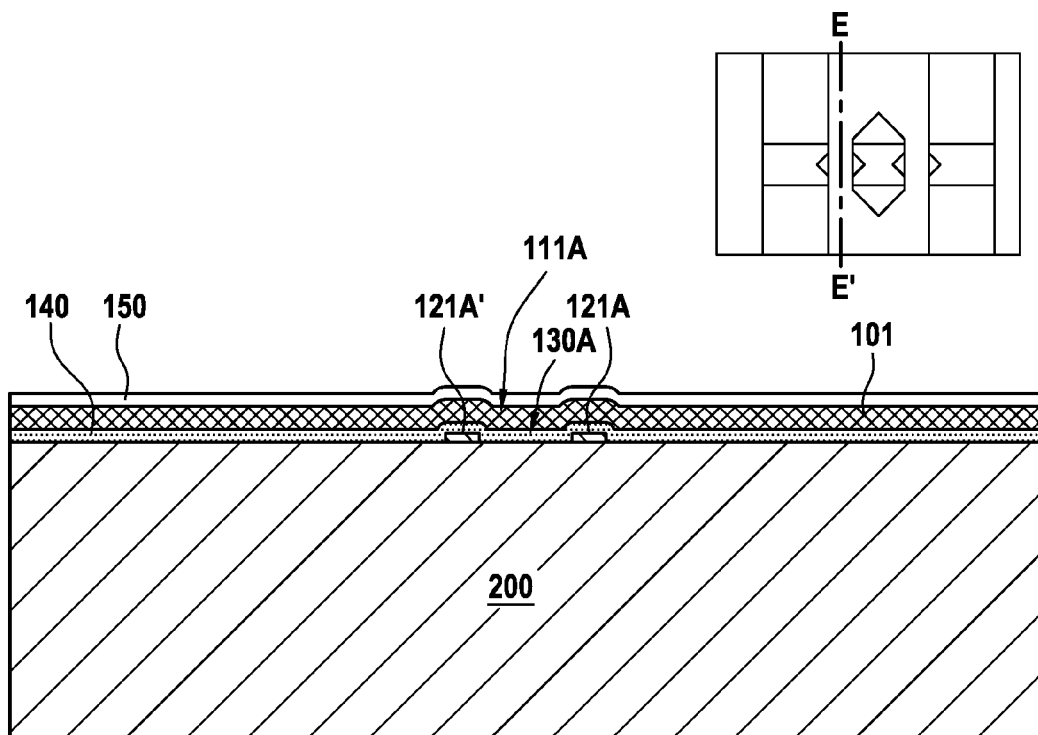


FIG. 7

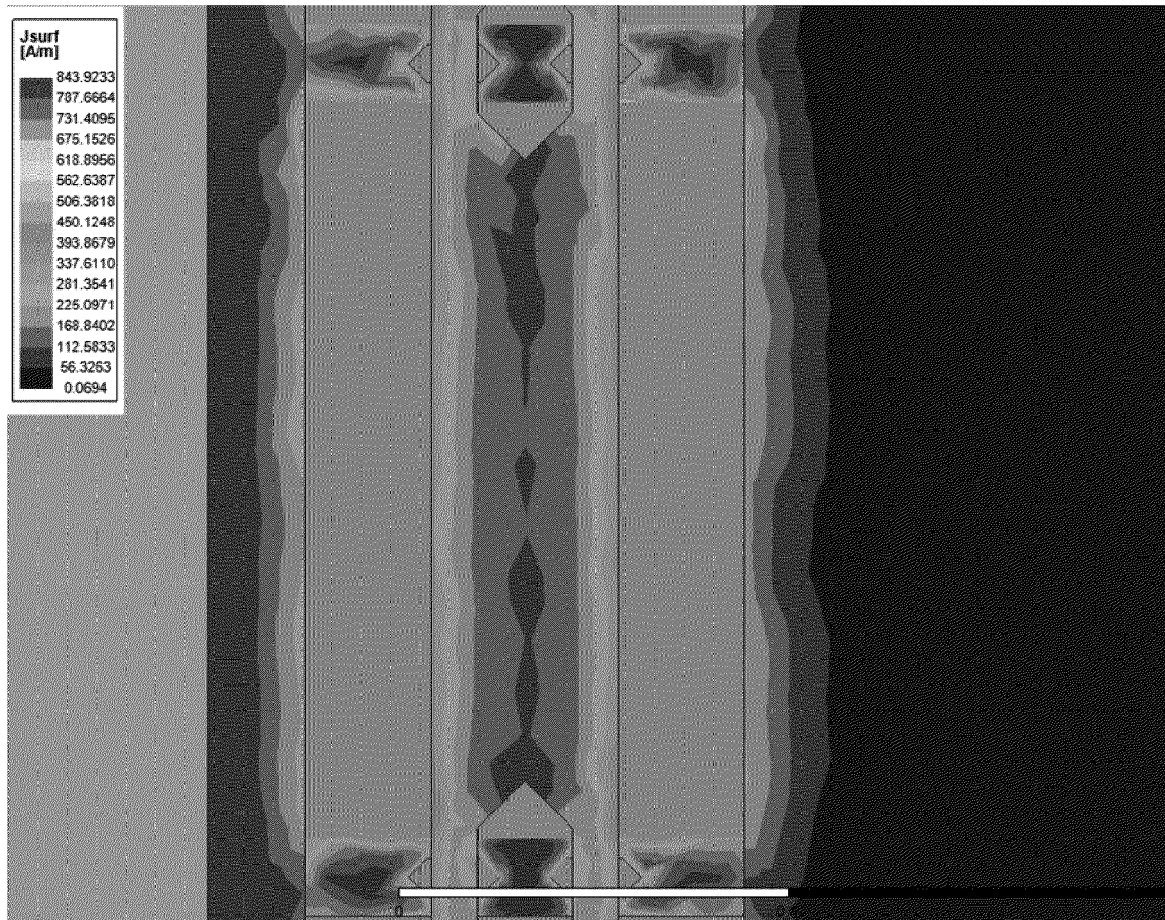


FIG. 8A

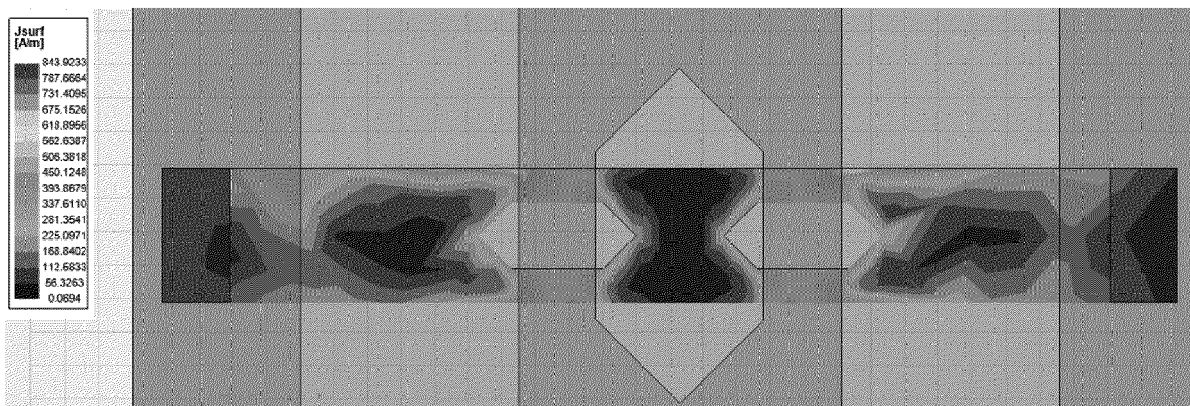


FIG. 8B

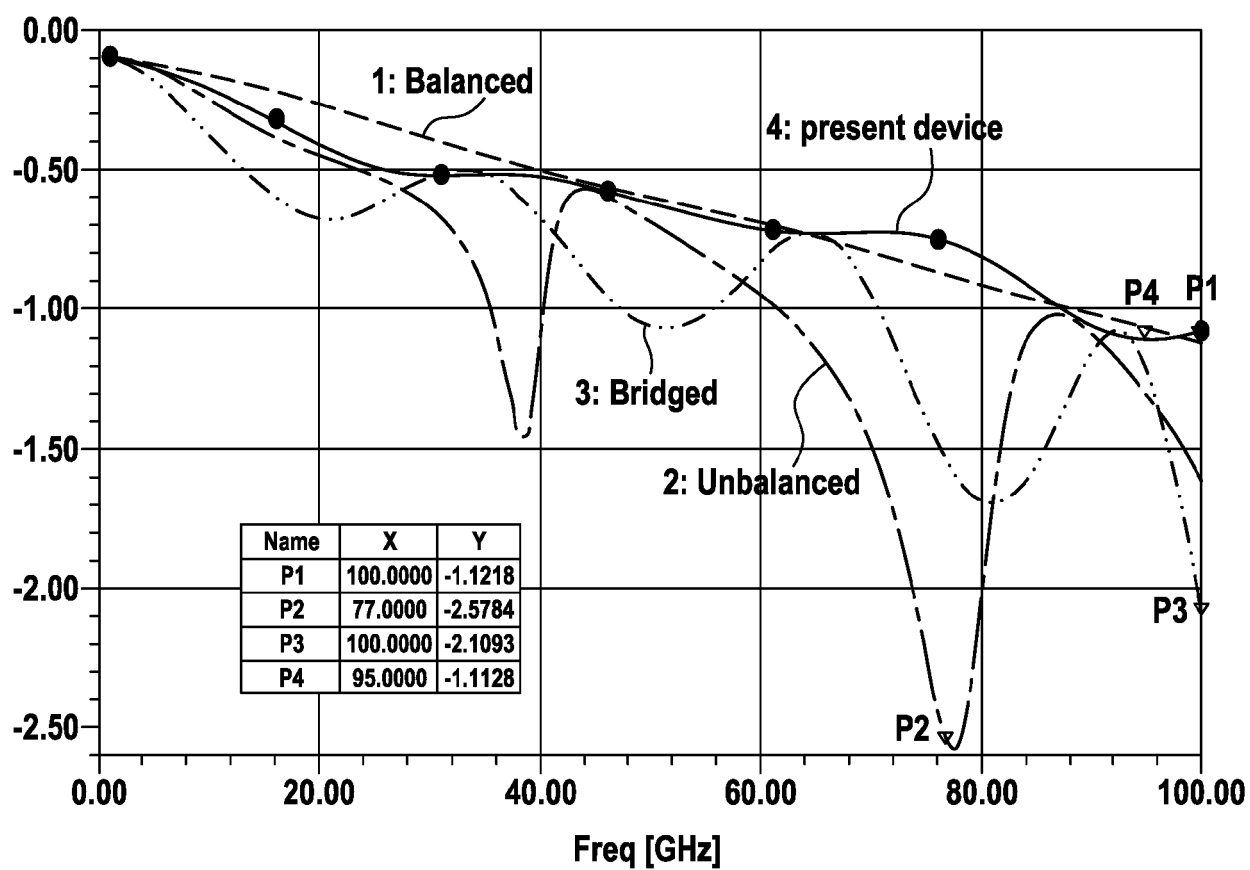


FIG.9



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